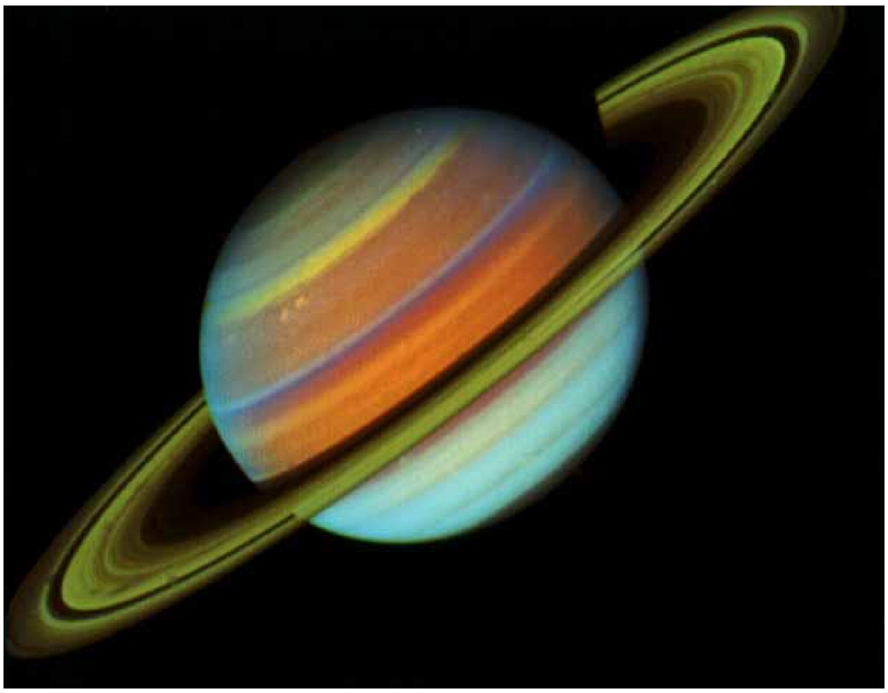
CHAPTER 1

A Mission of Discovery

Saturn, the second most massive planet in the solar system, offers us a treasure of opportunities for exploration and discovery. Its remarkable system of rings is a subject intensively studied, described and cataloged. Its planet-sized satellite, Titan, has a dense, veiled atmosphere. Some 17 additional icy satellites are known to exist — each a separate world to explore in itself. Saturn's magnetosphere is extensive and maintains dynamic interfaces with both the solar wind and with Titan's atmosphere.

From Observation to Exploration
Saturn was known even to the ancients. Noting the apparitions of the planets and recording other celestial events was a custom of virtually every early civilization. These activities knew no oceanic bounds, suggesting a curiosity universal to humankind. Real progress in understanding the planets came with the invention and use of instruments to accurately measure celestial positions, enabling astronomers to catalog the planets' positions.

Developments in mathematics and the discovery of the theory of gravitational attraction were also necessary steps. With the invention of the telescope and its first application in observing the heavens by Galileo Galilei, the pace of progress quickened.



Three separate images, taken by Voyager 2 through ultraviolet, violet and green filters, respectively, were combined to create this false-color image of Saturn.

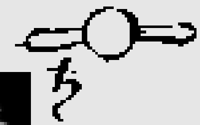
Today, the Cassini–Huygens mission to Saturn and Titan is designed to carry out in-depth exploration of the Saturn system. A payload of science instruments will make in situ measurements or observe their targets under favorable geometric and temporal circumstance. For example, an instrument might make observations over a range of various angles of illumination and emission, or study events such as occultations or eclipses.

Cassini–Huygens' interplanetary journey starts in October 1997, with the launch from Cape Canaveral in Florida. Upon arrival at Saturn, Cassini–Huygens will go into orbit about the planet. The spacecraft consists of two parts — the Cassini Orbiter and a smaller spacecraft, the Huygens Probe, which is targeted for Titan, Saturn's largest moon.

Huygens will arrive at Titan in November 2004. After using its heat shield for deceleration in Titan's upper atmosphere, Huygens will deploy a parachute system. Six instruments will make scientific measurements and observations during the long

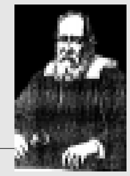
GETTING TO KNOW SATURN
A TIMELINE OF DISCOVERY

~ 800 BC Assyrian and Babylonian observations



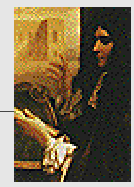
~ 300 AD Mythological view of Saturn the god

1610 Galileo notes the "triple planet" Saturn
with his telescope



1655–59 Huygens discovers Saturn's largest satellite, Titan

1671–84 Cassini discovers a division in the ring;
he also discovers the satellites Iapetus,
Rhea, Dione and Tethys



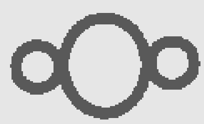
1789 Herschel discovers satellites Mimas and
Enceladus – and notes thinness of rings

1848 Bond and Lassel discover the satellite Hyperion

1850 Bond, Bond and Daws discover inner ring

1857 Maxwell proves that rings are not solid

1895 Keeler measures ring velocities



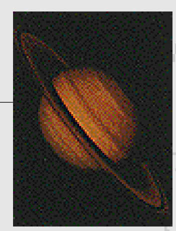
1898 Pickering discovers satellite Phoebe

1932 Wildt discovers methane and ammonia on Saturn

1943–44 Kuiper discovers methane and ammonia on Titan

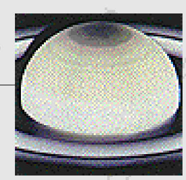
1979 Pioneer 11 flies past Saturn

1980 Voyager 1 encounters Saturn



1981 Voyager 2 encounters Saturn

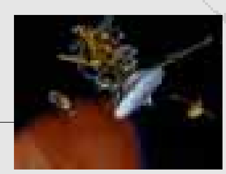
1989 Hubble Space Telescope's
Wide Field and Planetary Camera images Saturn



1995 Wide Field and Planetary Camera 2 images
ring plane crossing

1997 Cassini–Huygens launches

2004 Cassini–Huygens enters Saturn orbit;
Huygens explores Titan



descent to the surface. The Huygens Probe data will be transmitted to the Orbiter and then to Earth.

The Orbiter then commences a tour of the Saturn system. With its complement of 12 instruments, Cassini is capable of making a wide range of in situ and remote-sensing observations. The Orbiter will make repeated close flybys of Titan to make measurements and obtain observations.

The flybys of Titan will also provide gravity-assisted orbit changes, enabling the Orbiter to visit other satellites and parts of the magnetosphere and observe occultations of the rings and atmospheres of Saturn and Titan. Over the span of the four-year-long orbital mission, Cassini is expected to record temporal changes in many of the properties that it will observe.

Vision for a Mission

The Cassini–Huygens mission honors two astronomers who pioneered modern observations of Saturn. The Orbiter is named for Jean-Dominique Cassini, who discovered the satellites Iapetus, Rhea, Dione and Tethys, as well as ring features such as the Cassini division, in the period 1671–1684. The Titan Probe is named for Christiaan Huygens, who discovered Saturn's largest satellite in 1655.

The mission is a joint undertaking by the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The Huygens Probe is supplied by ESA and the main spacecraft — the Orbiter — is provided by NASA. The Italian space agency (Agenzia Spaziale Italiana, or ASI), through a bilateral agreement with NASA, is providing hardware systems for the Orbiter spacecraft and instruments. Other instruments on the Orbiter and the Probe are provided by scientific groups and / or their industrial partners, supported by NASA or by the national funding agencies of member states of ESA. The launch vehicle and launch operations are provided by NASA. NASA will also provide the mission operations and telecommunications via the Deep Space Network (DSN). Huygens operations are carried out by ESA from its operations center in Darmstadt, Germany.

Late in 1990, NASA and ESA simultaneously selected the payloads for the Orbiter and for the Huygens Probe, respectively. Both agencies also selected interdisciplinary investigations. The NASA Orbiter selection comprises seven principal investigator instruments, five facility instruments and seven interdisciplinary investigations. The ESA Huygens selection comprises six principal investigator instruments and three interdisciplinary scientist investigations.

This complex, cooperative undertaking did not come into being overnight. Rather, it was the end product of a process of joint discussions and careful planning. The result — the Cassini–Huygens mission — is an enterprise that, from the initial vision to the completion of the nominal mission, will span nearly 30 years! The formal beginning was in 1982, when a Joint Working Group was formed by the Space Science Committee of the European Science Foundation and the Space Science Board of the National Academy of Sciences in the United States.

The charter of the group was to study possible modes of cooperation between the United States and Europe in the field of planetary science. The partners were cautious and did not enter lightly into the decision to carry out the Cassini–Huygens mission. Their precept was that the mission would be beneficial for the scientific, technological and industrial sectors of their countries.

The Quest for Understanding

In carrying out this voyage, we are following a basic, evolutionally nurtured instinct to explore our environment. Whether exploration results in the discovery of resources or the recognition of hazards, or merely provides a sense of place or accomplishment, it has always proved beneficial to be familiar with our environment.

It is not surprising, therefore, that such exploration is a hallmark of growing, thriving societies. Parallels can be drawn between historical voyages of exploration and the era of solar system exploration. Available technology, skilled labor, possible benefits, cost, risk and trip duration continue to be some of the major considerations in deciding — to go or not to go? All these factors were weighed for Cassini–Huygens — and we decided to go.

In traveling to Saturn with Cassini–Huygens, we will also be satisfying a cultural desire to obtain new knowledge. This drive is very strong because modern society places a very high value on knowledge. For example, the whole field of education is focused on transferring knowledge to new generations. Often, a substantial portion of a person's existence is spent in school. The resources expended in creating new knowledge through inventions, research and scholarship are considered to be investments, with the beneficial return to come later. Knowledge is advantageous to us.

With Cassini–Huygens, we do not have to wait for our arrival at Saturn, because the return of new knowledge has already occurred. The challenge of this mission has resulted in new technological developments and inventions. Some of these have already been spun off to new applications, and new benefits are being realized now. But as with any investment, the main return is expected later, when Cassini–Huygens carries out its mission at Saturn.

Cassini–Huygens is the next logical step in the exploration of the outer solar system. The Jupiter system has been explored by Galileo. Now it is Saturn's turn. With Cassini–Huygens, we will explore in depth a new part of the solar system. Not only will we learn about the Saturn system, but as a result we will also learn more about Earth as a part of the solar system — rather than as an isolated planet.

Physics and chemistry are the same everywhere. Thus, knowledge gained about Saturn's magnetosphere or Titan's atmosphere will have application here on Earth. Interactions with the solar wind and impacts of comets and asteroids are just two of the processes that planets have in common. Information gleaned at Saturn about these shared histories and processes will also lead us to new information about Earth and its history.

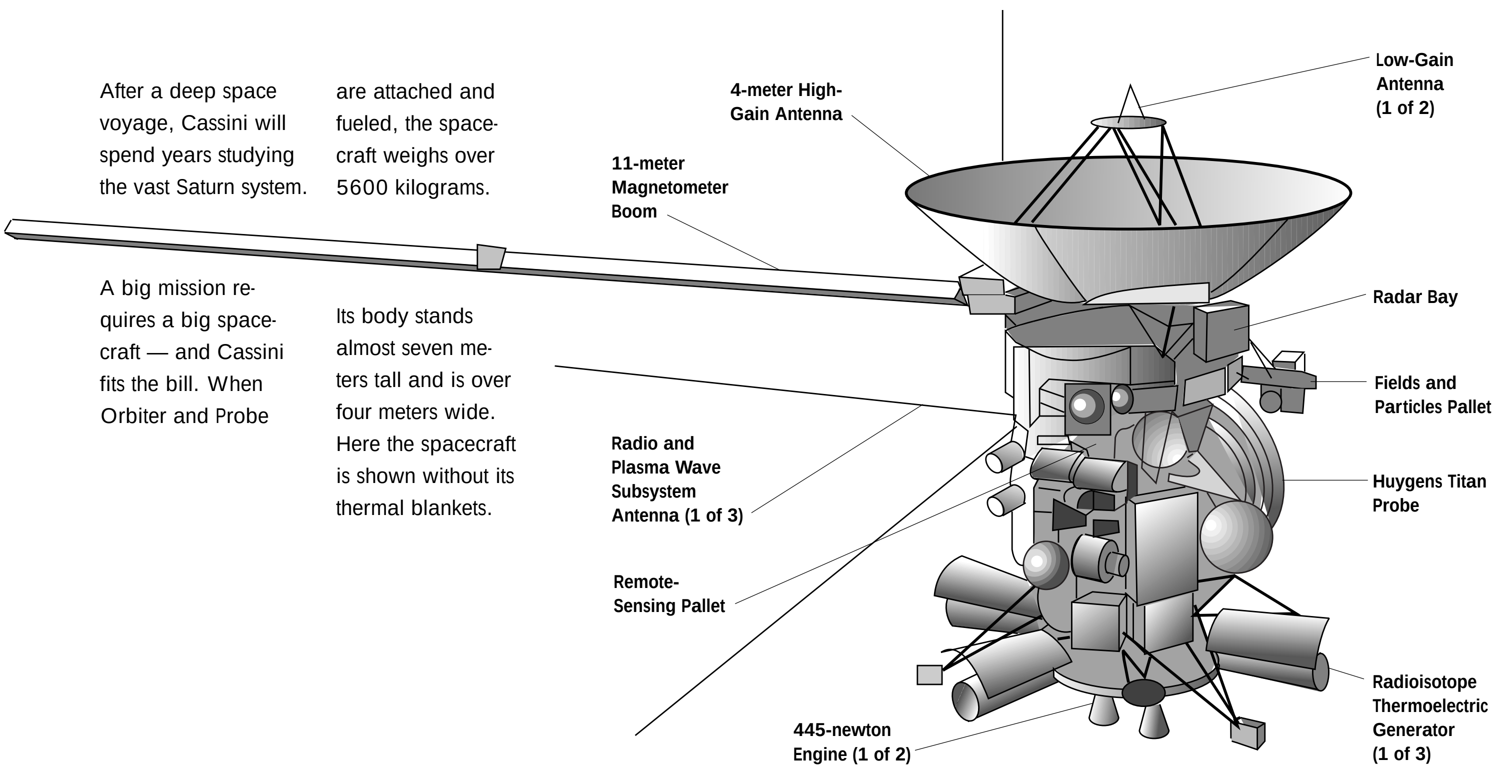
The Cassini–Huygens mission also allows the realization of other goals. Bringing people of different countries together to work toward a common goal promotes understanding and common values. The international character of Cassini–Huygens permits talented engineers and scientists to

VEHICLE OF DISCOVERY

After a deep space voyage, Cassini will spend years studying the vast Saturn system.

A big mission requires a big spacecraft — and Cassini fits the bill. When Orbiter and Probe are attached and fueled, the spacecraft weighs over 5600 kilograms.

Its body stands almost seven meters tall and is over four meters wide. Here the spacecraft is shown without its thermal blankets.



address the challenges of the mission. More people will share in the discoveries, the costs and the benefits.

About three quarters of a million people from more than 80 countries have involved themselves in the Cassini–Huygens mission by requesting that their signatures be placed aboard the spacecraft for the trip to the Saturn system. What will the mission bring to these people? The answers are varied: satisfaction of curiosity, a sense of participation, aesthetic inspiration, perhaps even understanding of our place in this vast universe.

The Spacecraft

At the time of launch, the mass of the fully fueled Cassini spacecraft will be about 5630 kilograms. Cassini consists of several sections. Starting at the bottom of the "stack" and moving upward, these are the lower equipment module, the propellant tanks together with the engines, the upper equipment module, the 12-bay electronics compartment and the high-gain antenna. These are all stacked vertically on top of each other. Attached to the side of the stack is an approximately three-meter-diameter, disk-shaped spacecraft — the Huygens Titan Probe. Cassini–Huygens accommodates some 27 scientific investigations, supported by 18 specially designed instruments: 12 on the Orbiter and six on the Probe.

Most of the Orbiter's scientific instruments are installed on one of two body-fixed platforms — the remote-sensing pallet or the fields and particles pallet — named after the type of instruments they support. The big, 11-meter-long boom supports sensors for the magnetometer experiment. Three thin 10-meter-long electrical antennas point in orthogonal directions; these are sensors for the Radio and Plasma Wave Science experiment. At the top of the stack is the large, four-meter-diameter high-gain antenna. Centered and at the very top of this antenna is a relatively small low-gain antenna. A second low-gain antenna is located near the bottom of the spacecraft.

Two-way communication with Cassini will be through NASA's Deep Space Network (DSN) via an X-band radio link, which uses either the four-meter-diameter high-gain antenna or one of the two low-gain antennas. The high-gain antenna is also used for radio and radar experiments and for receiving signals from Huygens.

The electrical power for the spacecraft is supplied by three radioisotope thermoelectric generators. Cassini is a three-axis-stabilized spacecraft. The attitude of the spacecraft is changed by using either reaction wheels or the set of 0.5-newton thrusters. Attitude changes will be done frequently because the instruments are body-fixed and the whole spacecraft must be turned in order to point them. Consequently, most of the observations will be made without a real-time communications link to Earth. The data will be stored on two solid-state recorders, each with a capacity of about two gigabits.

Scientific data will be obtained primarily by using one or the other of two modes of operation. These modes have been named after the functions they will carry out and are called the "remote-sensing mode" and the "fields and particles and downlink mode."

During remote-sensing operations, the recorders are filled with images and spectroscopic and other data that are obtained as the spacecraft points to various targets. During the fields and particles and downlink mode, the high-gain antenna is pointed at Earth and the stored data are transmitted to the DSN. Also, while in this mode, the spacecraft is slowly rolled about the axis of the high-gain antenna. This allows sensors on the fields and particles pallet to scan the sky and determine directional components for the various quantities they measure.

Mission Overview

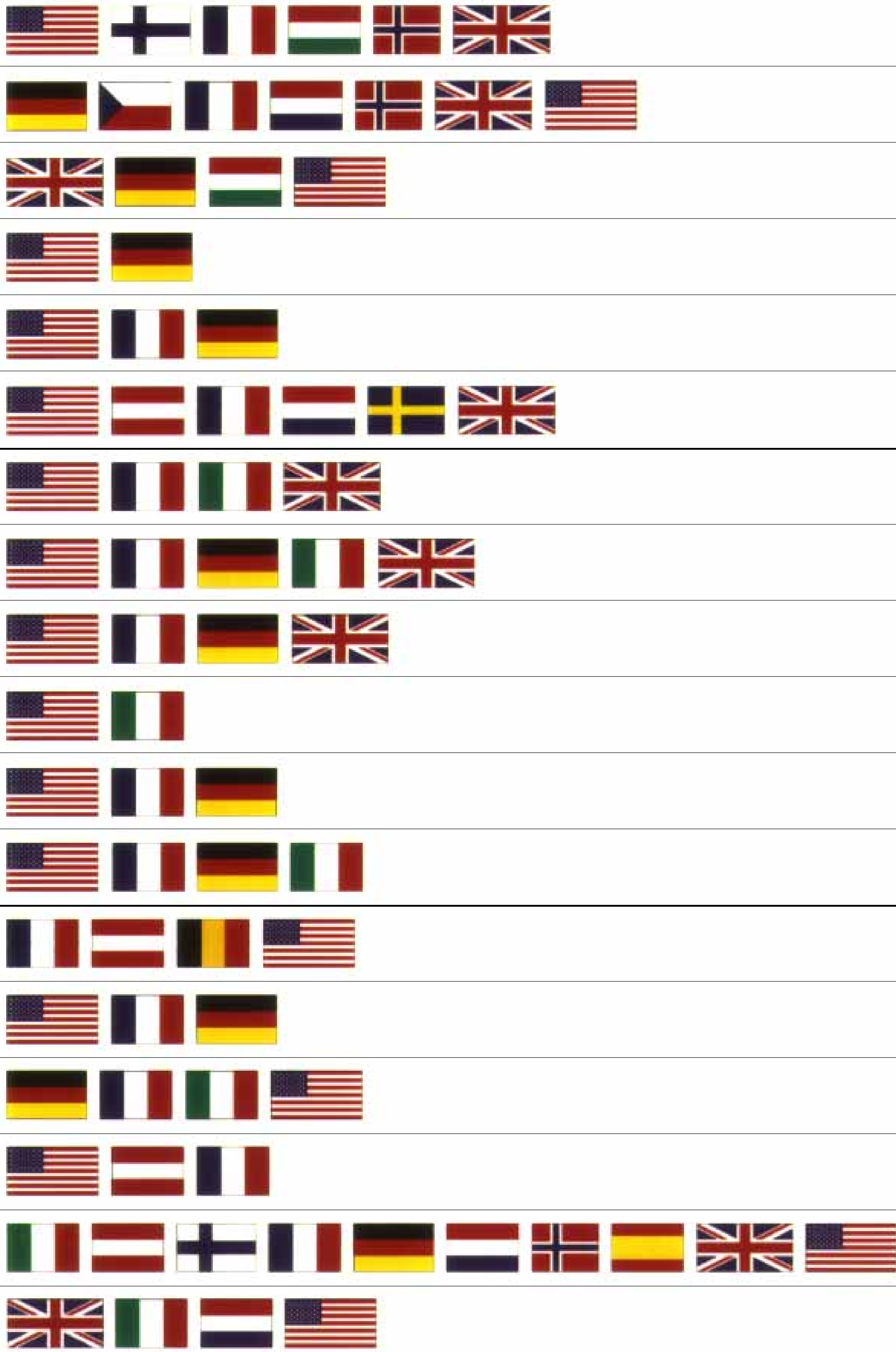
The Cassini–Huygens mission is designed to explore the Saturn system and all its elements — the planet Saturn and its atmosphere, its rings, its magnetosphere, Titan and many of the icy satellites. The mission will pay special attention to Saturn's largest moon, Titan, the target for Huygens.

The Cassini Orbiter will make repeated close flybys of Titan, both for gathering data about Titan and for gravity-assisted orbit changes. These maneuvers will permit the achievement of a wide range of desirable characteristics on the individual orbits that make up the tour. In turn, this ability to change orbits will enable close flybys of icy satellites, re-

CASSINI–HUYGENS SCIENCE INVESTIGATIONS

	Instrument	Investigations
Cassini Saturn Orbiter Fields and Particles Instruments	Cassini Plasma Spectrometer	In situ study of plasma within and near Saturn's magnetic field
	Cosmic Dust Analyzer	In situ study of ice and dust grains in the Saturn system
	Dual Technique Magnetometer	Study of Saturn's magnetic field and interactions with the solar wind
	Ion and Neutral Mass Spectrometer	In situ study of compositions of neutral and charged particles within the magnetosphere
	Magnetospheric Imaging Instrument	Global magnetospheric imaging and in situ measurements of Saturn's magnetosphere and solar wind interactions
	Radio and Plasma Wave Science	Measurement of electric and magnetic fields, and electron density and temperature in the interplanetary medium and within Saturn's magnetosphere
Cassini Saturn Orbiter Remote-Sensing Instruments	Cassini Radar	Radar imaging, altimetry, and passive radiometry of Titan's surface
	Composite Infrared Spectrometer	Infrared studies of temperature and composition of surfaces, atmospheres and rings within the Saturn system
	Imaging Science Subsystem	Multispectral imaging of Saturn, Titan, rings and icy satellites to observe their properties
	Radio Science Instrument	Study of atmospheric and ring structure, gravity fields and gravitational waves
	Ultraviolet Imaging Spectrograph	Ultraviolet spectra and low-resolution imaging of atmospheres and rings for structure, chemistry and composition
	Visible and Infrared Mapping Spectrometer	Visible and infrared spectral mapping to study composition and structure of surfaces, atmospheres and rings
Huygens Titan Probe Instruments	Aerosol Collector and Pyrolyser	In situ study of clouds and aerosols in Titan's atmosphere
	Descent Imager and Spectral Radiometer	Measurement of temperatures of Titan's atmospheric aerosols and surface imagery
	Doppler Wind Experiment	Study of winds by their effect on the Probe during descent
	Gas Chromatograph and Mass Spectrometer	In situ measurement of chemical composition of gases and aerosols in Titan's atmosphere
	Huygens Atmospheric Structure Instrument	In situ study of Titan's atmospheric physical and electrical properties
	Surface Science Package	Measurement of the physical properties of Titan's surface

Participant Nations*



* *First flag in each row represents nation of Principal Investigator or Team Leader.*

connaissance of the magnetosphere over a variety of locations and the observation of the rings and Saturn at various illumination and occultation geometries and phase angles.

The spacecraft will be injected into a 6.7-year Venus–Venus–Earth–Jupiter Gravity Assist (VVEJGA) trajectory to Saturn. Included are gravity assists from Venus (April 1998 and June 1999), Earth (August 1999) and Jupiter (December 2000). Arrival at Saturn is planned for July 2004.

During most of the early portion of the cruise, communication with the spacecraft will be via one of the two low-gain antennas. Six months after the Earth flyby, the spacecraft will turn to point its high-gain antenna at Earth and communications from then on will use the high-gain antenna.

Following the Jupiter flyby, the spacecraft will attempt to detect gravitational waves using Ka-band and X-band radio equipment. Instrument calibrations will also be done during cruise between Jupiter and Saturn. Science observations will begin two years away from Saturn (about one and a half years after the Jupiter flyby).

The most critical phase of the mission following launch is the Saturn orbit insertion (SOI) phase. Not only will it be a crucial maneuver, but it will also be a period of unique scientific activity, because at that time the spacecraft will be the closest it will ever be to the planet.

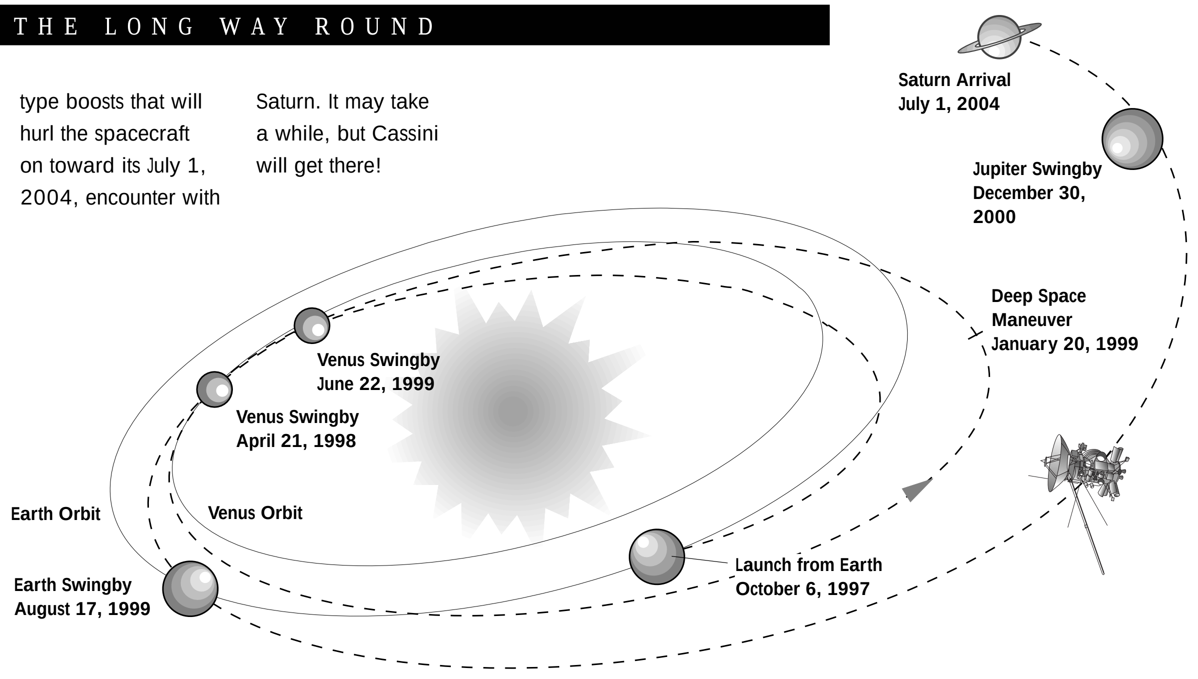
The SOI phase of the trajectory will also provide a unique opportunity for observing the rings. The spacecraft's first orbit will be the longest in the orbital tour. A periapsis-raise maneuver in September 2004 will establish the geometry for the Huygens Probe entry at the spacecraft's first Titan flyby in November.

Huygens' Encounter with Titan. In November 2004, the Huygens Probe will be released from the Cassini Orbiter, 21–22 days before the first Titan flyby. Two days after the Probe's release, the Orbiter will perform a deflection maneuver; this will keep the Orbiter from following Huygens into Titan's atmosphere. It will also establish the required radio-communication geometry between the Probe and the Orbiter, which is needed during the Probe descent phase, and will also set the initial conditions for the satellite tour — which starts right after the completion of the Probe mission.

The Huygens Probe has the task of entering Titan's atmosphere, making in situ measurements of the satellite's properties during descent by parachute to the surface. The Probe consists of a descent module enclosed by a thermal-protection shell. The front shield of this shell is 2.7 meters in di-

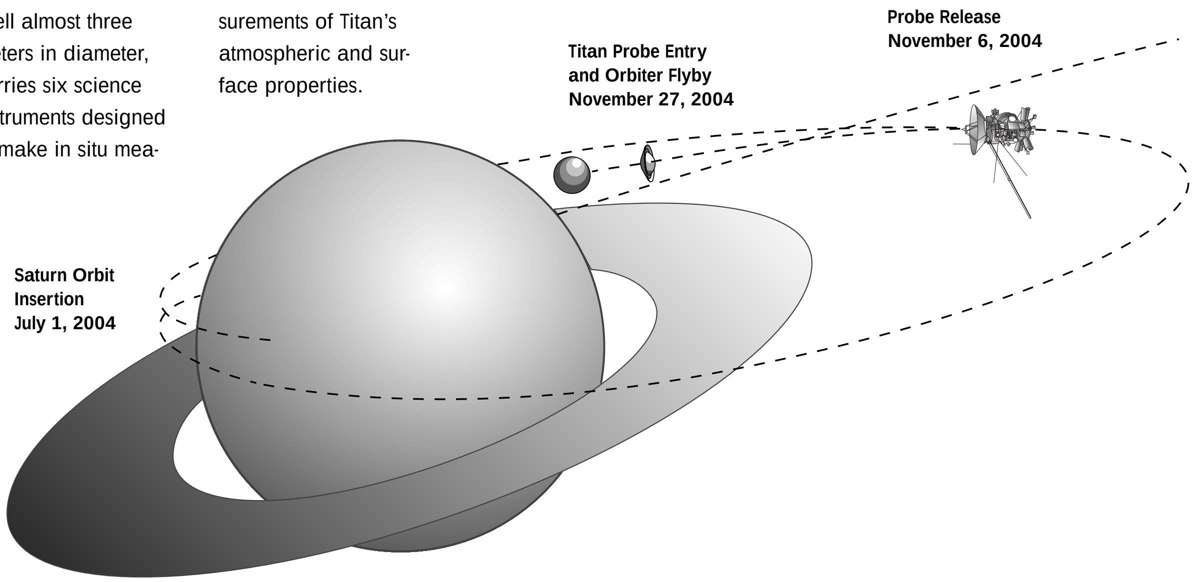
TAKING THE LONG WAY ROUND

Cassini will take nearly seven years to make the long trip from Earth to Saturn. Gravity assists from Venus (twice), Earth and Jupiter will give Cassini slingshot-type boosts that will hurl the spacecraft on toward its July 1, 2004, encounter with Saturn. It may take a while, but Cassini will get there!



PROBING A MOON OF MYSTERY

Huygens' encounter with Titan is planned for November 2004, about three weeks before the Orbiter makes its first flyby of Saturn's largest satellite. The Probe, which consists of a descent module enveloped by a conical thermal-protection shell almost three meters in diameter, carries six science instruments designed to make in situ measurements of Titan's atmospheric and surface properties.



ameter and is a very bluntly shaped conical capsule with a high drag coefficient. The shield is covered with a special thermal-ablation material to protect the Probe from the enormous flux of heat generated during atmospheric entry. On the aft side is a protective cover that is primarily designed to reflect away the heat radiated from the hot wake of the Probe as it decelerates in Titan's upper atmosphere. Atmospheric entry is a tricky affair — entry at too shallow an angle can cause the Probe to skip out of the atmosphere and be lost. If the entry is too steep, that will cause the Probe measurements to begin at a lower altitude than is desired.

After the Probe has separated from the Orbiter, the electrical power for its whole mission is provided by five lithium–sulfur dioxide batteries. The Probe carries two S-band transmitters and two antennas, both of which will transmit to the Orbiter during the Probe's descent. One stream of telemetry is delayed by about six seconds with respect to the other to avoid data loss if there are brief transmission outages.

Once the Probe has decelerated to about Mach 1.5, the aft cover is pulled off by a pilot parachute. An 8.3-meter-diameter main parachute is then deployed to ensure a slow and stable descent. The main parachute slows the Probe and allows the decelerator and heat shield to fall away.

To limit the duration of the descent to a maximum of two and a half hours, the main parachute is jettisoned at entry +900 seconds and replaced by a smaller, three-meter-diameter drogue chute for the remainder of the descent. The batteries and other resources are sized for a maximum mission duration of 153 minutes. This corresponds to a maximum descent time of two and a half hours, with at least three minutes — but possibly up to half an hour or more — on the surface, if the descent takes less time than expected.

The instrument operations are commanded by a timer in the top part of the descent and on the basis of measured altitude in the bottom part of the descent. The altitude is measured by a small radar altimeter during the last 10–20 kilometers.

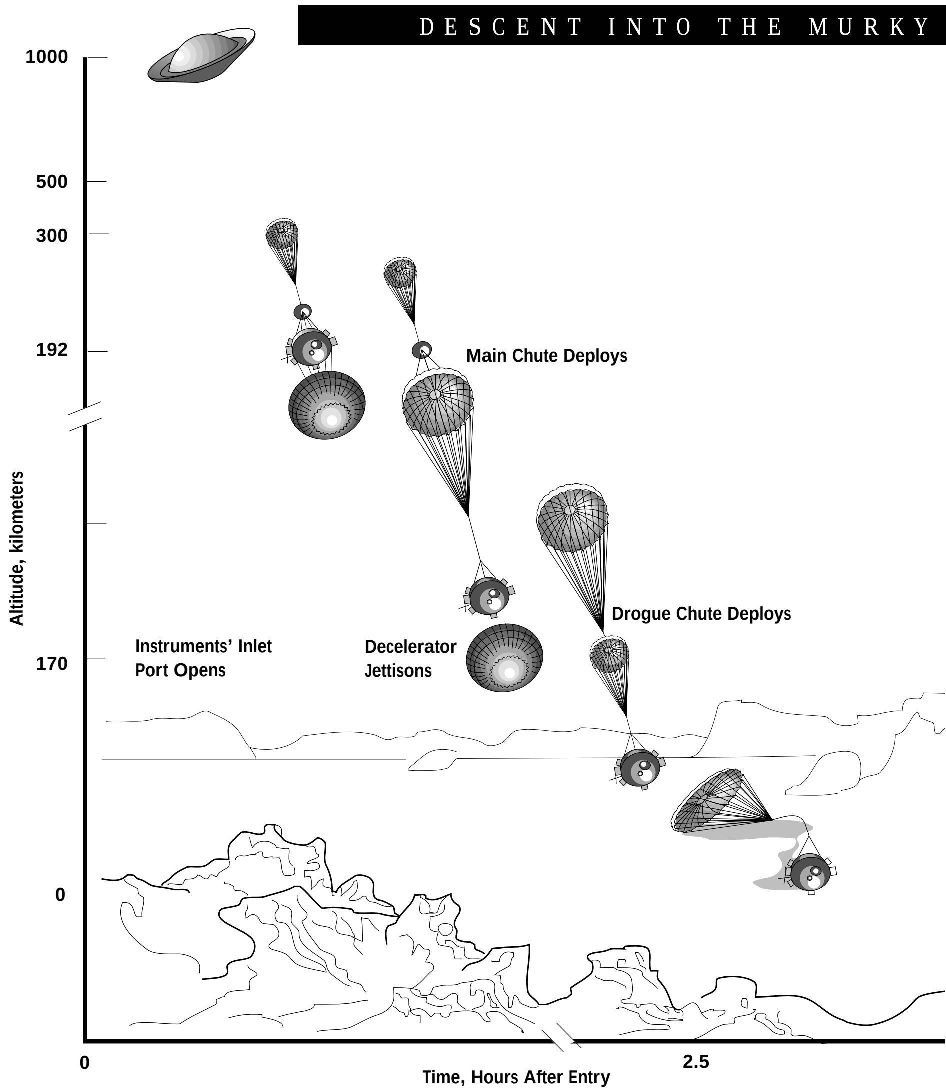
Throughout the descent, the Huygens Atmospheric Structure Instrument (HASI) will measure more than half a dozen physical properties of the atmosphere. The HASI will also process signals from the Probe's radar altimeter to gain information about surface properties. The Gas Chromatograph and Mass Spectrometer (GCMS) will determine the chemical composition of the atmosphere as a function of altitude. The Aerosol Collector and Pyrolyser (ACP) will capture aerosol particles, heat them and send the effused gas to the GCMS for analysis.

The optical radiation propagation in the atmosphere will be measured in all directions by the Descent Imager and Spectral Radiometer (DISR). The DISR will also image the cloud formations and the surface. As the surface looms closer, the DISR will switch on a bright lamp and measure the spectral reflectance of the surface. Throughout its descent, the Doppler shift of Huygens' telemetric signal will be measured by the Doppler Wind Experiment (DWE) equipment on the Orbiter to determine the atmospheric winds, gusts and turbulence.

In the proximity of the surface, the Surface Science Package (SSP) will activate a number of its devices to make measurements near and on the surface. If touchdown occurs in a liquid, such as in a lake or a sea, the SSP will measure the liquid's physical properties.

The Orbital Tour. After the end of the Probe mission, the Orbiter will start its nearly four-year tour, consisting of more than 70 Saturn-centered orbits, connected by Titan-gravity-assist flybys or propulsive maneuvers. The size of these orbits, their orientation to the Sun–Saturn line and their inclination to Saturn's equator are dictated by the various scientific requirements, which include Titan ground-track coverage; flybys of icy satellites, Saturn, Titan, or ring occultations; orbit inclinations; and ring-plane crossings.

DESCENT INTO THE MURKY DEPTHS



As Huygens' descent into Titan slows, it releases a small parachute, which then deploys the main parachute. The decelerator shield jettisons and the Probe drifts to about 40 kilometers above the surface. Then, a smaller, drogue chute carries Huygens the rest of the way to the surface.

TOUR T18-3
TARGETED SATELLITE FLYBYS*

Cassini Flybys, Planned	Saturn Satellite	Voyager Closest Approach, kilometers
1	Iapetus	909,000
4	Enceladus	87,000
1	Dione	162,000
1	Rhea	74,000

** Actual distances will be based on the type of observations planned.*

TOUR T18-3
SERENDIPITOUS SATELLITE FLYBYS*

Saturn Satellite	5000–25,000 kilometers	25,000–50,000 kilometers	50,000–100,000 kilometers	Voyager Flyby Range, kilometers
Mimas	–	1	4	88,000
Enceladus	3	–	3	87,000
Tethys	1	3	6	93,000
Dione	–	2	2	161,00
Rhea	–	1	1	74,000
Phoebe	–	1	–	2,076,000

** For flybys with closest approach on the sunlit side.*

Titan is the only Saturn satellite that is large enough to enable significant gravity-assisted orbit changes. The smaller icy satellites can help sometimes with their small perturbations, which can be useful in trimming a trajectory. Designing the Cassini orbital tour is a complicated and challenging task that will not be completed for at least several years.

One of the tours under consideration (called T18-3) can be used to illustrate the complexity involved in this type of navigational planning. T18-3 was the eighteenth tour designed for Cassini: This example is the third iteration of that tour. Tour T18-3 comprises 43 Titan flybys and seven "targeted" flybys of the icy satellites Iapetus, Enceladus, Dione and Rhea. "Targeted" means that the flyby distance can be chosen to best accommodate the planned observations — generally in the 1000-kilometer range. The closest approaches to the satellites made by the Voyager spacecraft in the early 1980s are used for reference.

In addition to the targeted flybys, there are other, unplanned — serendipitous — flybys that occur as a result of the tour path's geometry. If these flybys are close enough to the satellites, they will provide valuable opportunities for scientific observations. In our sample tour, T18-3, there are 28 of these flybys, with distances of less than 100,000 kilometers. At a range of 100,000 kilometers, the pixel resolution of Cassini's narrow-angle camera is about 0.6 kilometer for several of the icy satellites, providing better resolution than that achieved by Voyager.

Science Objectives

All the activities on Cassini–Huygens are pointed toward the achievement of the mission's science objectives. The origin of the objectives can be traced all the way back to the meetings of the Joint Working Group in 1982. They were further developed during the Joint NASA–ESA assessment study in 1984-85. As a result of this study, the science objectives appeared for the first time in their present form in the group's final report, issued by ESA in 1985. The objectives then became formally established with their inclusion in the NASA and ESA announcements of opportunity (ESA, 1989; NASA, 1989, 1991). The science objectives for Cassini–Huygens are organized by mission phase and target.

Scientific Objectives During Cruise. Given the trajectory for the long voyage to Saturn, Cassini–Huygens has the opportunity to carry out a number of experiments during the cruise phase. After launch, there will be instrument checkouts and maintenance activities. Searches for gravity waves will be carried out during the three successive oppositions of the spacecraft, beginning in December 2001.

These searches are radio experiments that involve using the DSN for two-way, K_a–band tracking of the spacecraft. During two solar conjunctions of the spacecraft, a series of radio-propagation measurements obtained from two-way X-band and K_a-band DSN tracking will provide a test of general relativity, as well as data on the solar corona.

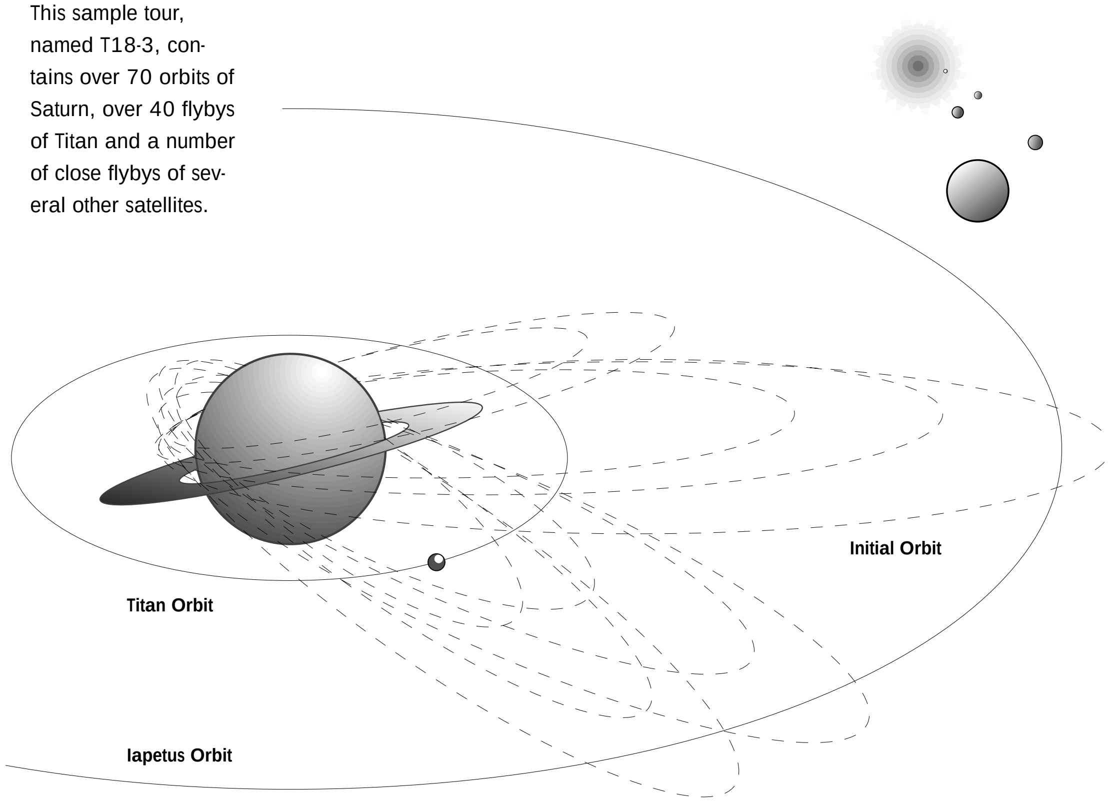
In early 1992, the Cassini project team at the Jet Propulsion Laboratory redesigned the mission and the Orbiter to meet NASA budgetary constraints expected for the following years. As a result, most of the science objectives for targets of opportunity — asteroid flyby, Jupiter flyby and cruise — were deleted. This was part of the effort to control development costs and the cost of operation during the first few years in flight. In the current baseline plan, the scientific data acquisition will start two years before arrival at Saturn; that is, well after the Jupiter flyby.

Scientific Objectives at Saturn. The list of scientific objectives for Cassini–Huygens is extensive. There are specific objectives for each of the types of bodies in the system — the planet itself, the rings, Titan, icy satellites and the magnetosphere. Not only is

ENCOUNTERS WITH A CELESTIAL GIANT

The actual makeup of Cassini's four-year "tour" of the Saturn system is yet to be finalized, but many possible scenarios are already under examination.

This sample tour, named T18-3, contains over 70 orbits of Saturn, over 40 flybys of Titan and a number of close flybys of several other satellites.



CASSINI–HUYGENS MISSION SCIENCE OBJECTIVES

SATURN

- Determine temperature field, cloud properties and composition of the atmosphere.
- Measure global wind field, including wave and eddy components; observe synoptic cloud features and processes.
- Infer internal structure and rotation of the deep atmosphere.
- Study diurnal variations and magnetic control of ionosphere.
- Provide observational constraints (gas composition, isotope ratios, heat flux) on scenarios for the formation and evolution of Saturn.
- Investigate sources and morphology of Saturn lightning (Saturn electrostatic discharges, lightning whistlers).

TITAN

- Determine abundances of atmospheric constituents (including any noble gases); establish isotope ratios for abundant elements; constrain scenarios of formation and evolution of Titan and its atmosphere.
- Observe vertical and horizontal distributions of trace gases; search for more complex organic molecules; investigate energy sources for atmospheric chemistry; model the photochemistry of the stratosphere; study formation and composition of aerosols.
- Measure winds and global temperatures; investigate cloud physics and general circulation and seasonal effects in Titan's atmosphere; search for lightning discharges.
- Determine physical state, topography and composition of surface; infer internal structure.
- Investigate upper atmosphere, its ionization and its role as a source of neutral and ionized material for the magnetosphere of Saturn.

MAGNETOSPHERE

- Determine the configuration of the nearly axially symmetrical magnetic field and its relation to the modulation of Saturn kilometric radiation.
- Determine current systems, composition, sources and sinks of the magnetosphere's charged particles.
- Investigate wave–particle interactions and dynamics of the dayside magnetosphere and magnetotail of Saturn, and their interactions with solar wind, satellites and rings.
- Study effect of Titan's interaction with solar wind and magnetospheric plasma.
- Investigate interactions of Titan's atmosphere and exosphere with surrounding plasma.

RINGS

- Study configuration of rings and dynamic processes (gravitational, viscous, erosional and electromagnetic) responsible for ring structure.
- Map composition and size distribution of ring material.
- Investigate interrelation of rings and satellites, including embedded satellites.
- Determine dust and meteoroid distribution in ring vicinity.
- Study interactions between rings and Saturn's magnetosphere, ionosphere and atmosphere.

ICY SATELLITES

- Determine general characteristics and geological histories of satellites.
- Define mechanisms of crustal and surface modifications, both external and internal.
- Investigate compositions and distributions of surface materials, particularly dark, organic rich materials and low-melting-point condensed volatiles.
- Constrain models of satellites' bulk compositions and internal structures.
- Investigate interactions with magnetosphere and ring system and possible gas injections into the magnetosphere.

CASSINI—HUYGENS
CHRONOLOGY OF A PLANETARY MISSION

1982

Space Science Committee of the European Science Foundation and the Space Science Board of the National Academy of Sciences form working group to study possible U.S.–European planetary science cooperation. European scientists propose a Saturn orbiter–Titan probe mission to the European Space Agency (ESA), suggesting a collaboration with NASA.

1983

U.S. Solar System Exploration Committee recommends NASA include a Titan probe and a radar mapper in its core program and also consider a Saturn orbiter.

1984–85

Joint ESA–NASA assessment study of a Saturn orbiter–Titan probe mission.

1987

ESA Science Program Committee approves Cassini for Phase A study, with conditional start in 1987.

1987–88

NASA carries out further definition and work on Mariner Mark 2 spacecraft and the missions designed to use it: Cassini and Comet Rendezvous/Asteroid Flyby (CRAF).

Titan probe Phase A study carried out by joint ESA/NASA committee, supported by European industrial consortium led by Marconi Space Systems.

1988

Selection by ESA of Cassini mission Probe to Titan as next science mission; Probe named Huygens.

1989

Funding for CRAF and Cassini approved by U.S. Congress. NASA and ESA release announcements of opportunity to propose scientific investigations for the Saturn orbiter and Titan probe.

1992

Funding cap imposed on CRAF/Cassini: CRAF canceled; Cassini restructured. Launch rescheduled from 1996 to 1997.

1995

U.S. House Appropriations Subcommittee targets Cassini for cancellation, but the action is reversed.

1996

Spacecraft and instruments integration and testing.

APRIL 1997

Cassini spacecraft shipped to Cape Canaveral, Florida.

SUMMER 1997

Final integration and testing.

OCTOBER 1997

Launch from Cape Canaveral, Florida.

APRIL 1998

First Venus gravity-assist flyby.

JUNE 1999

Second Venus gravity-assist flyby.

AUGUST 1999

Earth gravity-assist flyby.

DECEMBER 2000

Jupiter gravity-assist flyby.

DECEMBER 2001

First gravitational-wave experiment.

JUNE 12, 2004

Phoebe flyby; closest approach is 52,000 kilometers.

JULY 1, 2004

Spacecraft arrives at Saturn and goes into orbit around the planet.

NOVEMBER 6, 2004

Release of Huygens Probe on a trajectory to enter Titan's atmosphere.

NOVEMBER 27, 2004

Huygens returns data as it descends through Titan's atmosphere and reaches the surface; Orbiter begins tour of the Saturn system.

JULY 2008

Nominal end of mission.

Cassini–Huygens designed to determine the present state of these bodies and the processes operating on or in them, but it is also equipped to discover the interactions that occur among and between them.

These interactions within the Saturn system are important. An analogy can be drawn to a clock, which has many parts. However, a description of each part and the cataloging of its properties, alone, completely misses the "essence" of a clock. Rather, the essence is in the interactions among the parts. So it is for much of what the Cassini–Huygens mission will be studying in the Saturn system.

It is the ability to do "system science" that sets apart the superbly instrumented spacecraft. The very complex interactions that are in play in systems such as those found at Jupiter and Saturn can only be addressed by such instrument platforms. This is because the phenomena to be studied are often sensitive to a large number of parameters — a measurement might have to take into account simultaneous dependencies on location, time, directions to the Sun and planet, the orbital configurations of certain satellites, magnetic longitude and latitude and solar wind conditions. To deal with such complexity, the right types of instruments must be on the spacecraft to make all the necessary and relevant measurements — and all the measurements must be made essentially at the same time. Identical conditions very seldom, if ever, recur. Thus, it would be totally impossible for a succession, or even a fleet, of "simple" spacecraft to obtain the same result. Furthermore, requiring the instruments to operate simultaneously has a major impact on spacecraft resources such as electrical power. This demand — and the need for a broadly based, diverse collection of instruments — is the reason that the Cassini–Huygens spacecraft is so large.

Both the Huygens Probe and the Cassini Orbiter will study Titan. While the formal set of scientific objectives is the same for both, the Cassini–Huygens mission is designed so that a synergistic effect will be realized when the two sets of measurements are combined. In other words, the total scientific value of the two sets of data together will be maximized because of certain specific objectives for the Probe and the Orbiter. Each time the Orbiter flies by Titan, it will make atmospheric and surface remote-sensing observations that include re-observations along the flight path of the Probe. The Probe's measurements will be a reference set of data for calibrating the Orbiter's observations. In this way, the Probe and Orbiter data together can be used to study the spatial and seasonal variations of the composition and dynamics of the atmosphere.

Launch: Ending and Beginning

Launch is both an ending and a beginning. Nowhere is there a more profound test of the work that has been done, nor a more dramatic statement to mark a shift in program priorities. Nowhere is there more hope — or more tension. A successful launch is everything.

These will be our thoughts as we survey the scene at Cape Canaveral Air Station in Florida. It is October 6, 1997. The launch vehicle is the Titan IVB with two stout Solid Rocket Motor Upgrades (SRMUs) attached. An additional Centaur rocket — the uppermost stage — sits on top of the propulsion stack. This system puts Cassini–Huygens into Earth orbit and then, at the right time, sends it on its interplanetary trajectory.

The "core" Titan vehicle has two stages. The SRMUs are anchored to the first, or lower, stage. These "strap-on" rockets burn solid fuel; the Titan uses liquid fuel. The Centaur is a versatile, high-energy, cryogenic-liquid-fueled upper stage with two multiple-start engines. The Titan IVB/SRMU–Centaur system is capable of placing a 5760-kilogram payload into a geostationary orbit. On top of all this propulsive might sits Cassini–Huygens, protected for its trip through the lower atmosphere by a 20-meter-long payload fairing.

Lift-off is from Cape Canaveral Air Station, launch complex 40. It is early in the morning. The launch sequence begins with the ignition of the two solid-rocket motors, which lift the whole stack off the pad. About 10 seconds after lift-off, the stack continues to accelerate and then it starts to tilt and rotate. The rotation continues until the required azimuth is reached.

At plus two minutes, the first stage of the Titan is ignited, at an altitude of approximately 58,520 meters. A few seconds later, the two solid-rocket motors, now spent, are jettisoned. One and a half minutes pass, and at 109,730 meters, the payload fairing is released.

About five and a half minutes into the flight, the Titan reaches an altitude of 167,330 meters. Here the first stage of the Titan separates and the second stage fires. At launch plus nine minutes, the second stage has burnt out and drops away. Now it is the Centaur's turn to fire. It boosts the remaining rocket–spacecraft stack into a "parking" orbit around Earth and turns off its engines.

Some 16 minutes later, the Centaur ignites for a second time. This burn lasts between seven and eight minutes, and when it is over, the Centaur separates from the spacecraft. The Cassini–Huygens spacecraft is now on an interplanetary trajectory, heading first for Venus, then Venus again, around to Earth, to Jupiter — and at last, Saturn!